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Scenario Planning for U.S. Supply Chain Resilience:
Modeling the Impacts of Geopolitical Disruptions and Freight Cost Volatility

Scenario Planning for the Resilience of US Supply Chains: Modeling the Impacts of Geopolitical Disruptions and Freight Cost Volatility

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Summary

This article examines the use of **scenario planning** as a decision-making tool to strengthen the **resilience** of U.S. supply chains in the face of **geopolitical disruptions** (sanctions, conflicts, embargoes, regulatory shocks) and **freight cost volatility** (ocean, rail, road, and air). The paper integrates the **operations and risk** literature with **strategic intelligence** practices , proposing a method that links **plausible narratives** to **quantitative models** (discrete event simulation, system dynamics, and Monte Carlo), producing metrics for **TTS/TTR, OTIF, Operational VaR ,** and **avoided loss** under different trajectories. The paper argues that the usefulness of scenarios increases when coupled with **signposts** and **decision triggers** that activate **contractual optionalities, structural buffers ,** and **multi-gateway rerouting.** Evidence from industry reports and public policy frameworks—such as the **National Freight Strategic Plan** (USDOT)—suggests that the combination of **modular architecture, interorganizational data ,** and **option-based contracts**

reduces the area of the **resilience triangle** and protects margins in shocks (SHEFFI, 2015; CHOPRA; MEINDL, 2016; USDOT, 2020; UNCTAD, 2020; SEA-INTELLIGENCE, 2021).

Keywords: scenario planning; resilience; freight costs; geopolitics; TTS/TTR; United States.

Abstract

This paper examines **scenario planning** as a decision tool to strengthen the **resilience** of US supply chains against **geopolitical disruptions** (sanctions, conflicts, embargoes, regulatory shocks) and **freight cost volatility** (ocean, rail, truck, air). We integrate **operations and risk** literature with **strategic foresight** practices, proposing a method that links **plausible narratives** to **quantitative models** (discrete-event simulation, system dynamics and Monte Carlo), yielding **TTS/TTR, OTIF, Operational VaR** and **loss avoided** under alternative paths. We discuss scenarios are more useful when coupled with **sign posts** and **decision triggers** that activate **contractual options, structural buffers and multi-gateway rerouting.** Evidence from industry

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reports and policy frameworks—such as the **National Freight Strategic** Plan—suggests that combining **modular architectures, inter-organizational data,** and **option-based contracts** reduces the **resilience triangle** area and protects margins under shocks (SHEFFI, 2015; CHOPRA; MEINDL, 2016; USDOT, 2020; UNCTAD, 2020; SEA-INTELLIGENCE, 2021).

Keywords: scenario planning; resilience; freight costs; geopolitics; TTS/TTR; United States.

1. Fundamentals and Scope: Why Scenarios for US Chains Under Geopolitics and Volatile Freight

Scenario planning was born to deal with **deep uncertainty** —the kind in which statistical extrapolations lose validity—and migrated from the energy sector to operations and risk due to its ability to **explore multiple futures** without claiming to predict specific situations (WACK, 1985; SCHOEMAKER, 1995). In US supply chains, the turbulence of the 2018–2021 period highlighted how **trade policy shocks, cross-sanctions ,** and **logistical constraints** can alter **total costs** and **door-to-door times** within weeks , overcoming planned slack and disrupting **S&OP/S&OE** (SHEFFI, 2015; CHOPRA; MEINDL, 2016).
Unlike linear contingency plans, scenarios **explore combinations** of forces (geopolitics × freight × energy × climate) and **chain effects** (ports-railways-highways), offering a framework for **deciding before** the crisis what to activate **during** the crisis.

The first conceptual foundation is to distinguish **measurable risk** from **non-probabilistic uncertainty.** Freight costs have distributions that can be parameterized based on indices (spot and contracts, *bunker* and diesel), but **geopolitical disruptions** have discrete dynamics (sanctions, embargoes, conflicts, canal closures) that discontinuously shift **regimes** (UNCTAD, 2020; EIA, 2021). Scenarios allow us **to represent regimes** and **transitions,** rather than insisting on historical averages that mask **the fat tails** observed in 2020–2021 (SEA-INTELLIGENCE, 2021). In resilience terms, we think of **states** (normal, degraded, critical) and **transition times** (TTR) conditioned by mitigation policies.

The second fundamental is the **maritime-land coupling** in the North American network. Port hubs such as **LA/Long Beach, NY/NJ, Savannah, Houston ,** and **Gulf** gateways feed rail corridors (BNSF, UP, CSX, NS) and **interstates ,** which in turn modulate **total cost** and **delivery time** to *fulfillment centers* and factories. **Geopolitical scenarios** that alter **Asian origins** (China+1 reconfiguration, Taiwan-Strait risk) or **oceanic routes** (Suez/Panama) **propagate** to docking windows, **schedule reliability ,** and truck **turn times ,** requiring **network treatment,** not isolated link treatment (USDOT, 2020; NOTTEBOOM; RODRIGUE, 2021). Scenario logic, therefore, needs to **traverse interfaces.**

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The third fundamental is the **economics of options.** In volatile freight environments, **contractual optionalities** (capacity reservations, multi-gateway, *box pools,* flexible *take-or-pay)* function as **operational insurance** that shifts part of the *spike* risk to ex-ante mechanisms (CHRISTOPHER, 2016; SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008). Scenarios help **price** these options based on **avoided loss** and **TTR reduction,** allowing the board to compare alternatives not only by **average cost per unit,** but also by **downside protected** in shocks—a metric more faithful to the objective of **financial resilience.**

The fourth foundation is **data governance and early warning signs.** Scenarios shouldn't be left on *slides;* they need operational and macro-level **signposts** (e.g., **persistent decline in *schedule reliability).*** on trans-Pacific services, **abnormal variations** in AIS/anchorage time, **movement in sanctions** and **energy** via EIA) that **activate** pre-agreed triggers—opening **extended windows, diverting gateways, exercising capacity options, activating container pools** (IAPH, 2020; SEA-INTELLIGENCE, 2021). This link between **narrative-signal-trigger** is what converts scenarios into **reaction capacity.**

The fifth foundation is **regulatory and sectoral alignment.** In the US, frameworks such as the **National Freight Strategic Plan** and **continuity** guidelines (ISO 22301) reinforce the need for **intermodal cooperation, data standardization ,** and criticality- **driven investments** (USDOT, 2020; ISO 22301, 2019). In terms of scenarios, this means considering **regulatory constraints** (hours of service, weight/height *permits , driver shortages),* as **theoretical options** may be unfeasible under certain rules; therefore, the **feasibility** of each response needs to be tested against **normative constraints.**

The sixth fundamental is **geographic and energy-related. Ocean diversions** and **air routes** in crisis alter fuel consumption and **cost curves** (bunker/diesel/jet-A), with almost immediate impact on **truckload, intermodal ,** and **air cargo** rates (EIA, 2021; UNCTAD, 2020). Plausible scenarios should **co-simulate** energy prices and **modal capacity,** because simultaneous *spikes* in bunker and diesel prices can reduce the attractiveness of certain routes, pushing cargo onto **rail.** or **aerial** and requiring **mix re-planning.**

The seventh principle is **organizational:** scenarios only produce value when **linked to S&OP/ S&OE** and the **budget cycle,** with **TTS/TTR targets, loss limits ,** and **mitigation portfolios** already approved for activation. This avoids **decision-making latency** and jurisdictional disputes amid shocks (SHEFFI, 2015; CHRISTOPHER, 2016). In other words, scenarios are **operational pre-agreements** informed by analysis, not exercises of imagination.

Finally, the eighth fundamental is **metric:** a scenario's usefulness is measured by its ability to reduce the **area of the resilience triangle** (drop × duration) and preserve **margin** and **service levels** under adverse trajectories. This requires translating narratives into **TTS/TTR, OTIF, backlog clearing, demurrage/detention, premium freight ,** and **Operational VaR,** allowing for the comparison of mitigation **portfolios** by **impact/cost** (PONOMAROV; HOLCOMB, 2009; SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008; SEA-INTELLIGENCE, 2021).

2. Construction and modeling method: from *axes-of-uncertainty* to digital twins and *stress-tests*

The proposed method starts with the *axes-of-uncertainty* **framework ,** mapping two to three dimensions that best explain variation in **total cost** and **door-to-door time** in US supply chains: **(i)** geopolitical *status* (cooperation ÿ confrontation); **(ii) freight and energy** regime (stable ÿ volatile with tails); **(iii) port/ intermodal capacity** (unobstructed ÿ congested).
The combination of these axes generates a **portfolio of extreme and intermediate scenarios** (WACK, 1985; SCHOEMAKER, 1995). For each quadrant, causally coherent **storylines** are defined: for example, "Confrontation + Volatility + Congestion" incorporates **sanctions** that displace Asian flows, bunker/diesel **spikes , falling *schedule reliability* ,** and **queues** at Pacific gateways; the opposite describes detente, stable fuels, and **demand-capacity balance.**

The second step translates **storylines** into **quantifiable drivers.** For geopolitics: **tariffs** and **sanctions** in product classes, **export restrictions, partial** canal closures, and **security rules;** for freight/energy: **bunker/diesel/jet-A curves** and tariff elasticities by mode (UNCTAD, 2020; EIA, 2021); for capacity: **schedule reliability** by service, **queue/berthing time, quay productivity ,** and **truck/rail turn times** (SEA-INTELLIGENCE, 2021; WORLD BANK, 2020). These drivers feed **coupled models** that will represent **propagation** (maritime ÿ port ÿ hinterland) and **response** (buffers, diversion, options).

The third step is to select **modeling tools. Discrete Event Simulation (DES)** represents interconnected queues at the pier, yard, gate, and rail; **system dynamics (SD)** captures stocks/flows and **feedbacks** (bullwhip effect, accumulated backlog); **agent-based models (ABM)** introduce **adaptive behaviors** (rolling, SLA-based prioritization, route selection by drivers/operators) (IVANOV; DOLGUI, 2020; CHOPRA; MEINDL, 2016). **Monte Carlo** adds **variability** to the drivers (price, reliability, arrival), producing **probabilistic ranges** of TTR and cost. In practice, a **digital twin** of the trans-Pacific or trans-Atlantic corridor integrates DES+SD+ABM with **AIS/TOS/PCS data.**

The fourth step defines **output metrics** that matter to the decision maker: **TTS/TTR** per node/corridor, sea-to-land **OTIF , backlog clearing time, demurrage/detention, freight premium ,** and **preserved margin.** Additionally, **Operational VaR** (expected tail loss) and **Expected Shortfall** are calculated under each scenario, allowing for comparison of mitigation **portfolios** by **avoided loss per dollar** (PONOMAROV; HOLCOMB, 2009; SHEFFI, 2015). The **area of the resilience triangle** summarizes the temporal effectiveness of each policy, while **response curves** show how TTR drops with **extended windows, off-dock, multi-gateway ,** or **capacity options.**

The fifth stage incorporates **options and triggers.** Each scenario receives **activation rules:** “If *schedule reliability* < X% for Y weeks, **exercise option** on alternate service; if **queue > Z hours** at gateway A, **divert** X% to gateway B; if **diesel** and **bunker** exceed bandwidths, **migrate** part of the

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volume for **rail."** These **contingent policies** are simulated to measure **TTR** and **total cost** under different shock **sequences ,** recognizing that activation **timing** is as relevant as the choice of measure (SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008; CHRISTOPHER, 2016).

The sixth stage defines **signal posts** — **leading-consequent indicators** that monitor the proximity of a scenario—and **confidence thresholds** for triggering. Examples include **persistent declines** in trans-Pacific reliability (LPG/Sea-Intelligence), **abnormally increased docking times** (AIS), **variations** in **tariffs and sanctions** (Official Gazette), simultaneous **spikes** in **bunker/diesel prices** (EIA), and ***driver shortage* signals** (vacancies, highway *spot rates).* These signals feed **control towers** and **S&OP/S&OE,** reducing **decision-making latency** (IAPH, 2020; USDOT, 2020).

The seventh step is **validation and *stress testing.*** The digital twin needs to be **calibrated** with historical data (2018–2021) and **cross-validated** (e.g., to reproduce the 2021 reliability drop and observed queue times at gateways). Then, **extreme scenarios** are applied. ("plausible black swans") to evaluate **TTR ranges** and **dominant bottlenecks** (WORLD BANK, 2020; NOTTEBOOM; RODRIGUE, 2021). Validation avoids **laboratory optima** and lends **credibility** to the model's use in capital and contract decisions.

The eighth stage integrates **governance:** scenarios leave the risk team and enter the **budget cycle** with **TTR/OTIF targets, VaR limits, mitigation portfolios ,** and **responsible parties; playbooks** are versioned; post-event **AARs** feed *lessons learned;* and **KPIs** are included in **executive bonuses** (ISO 22301, 2019; SHEFFI, 2015). The result is a **repeatable process,** in which scenarios inform **where to integrate** (control) and **where to modularize** (options), with **data and contracts** serving as *rails* for execution.

3. Freight and Transmission Cost Structures for *Total Landed* Cost (TLC)

The starting point for modeling the impact of geopolitical shocks and volatility is to break down **freight costs** into their components and understand how each component propagates to the **Total Landed Cost (TLC).** In **ocean freight,** in addition to the **base rate,** these include **BAF** (bunker adjustment factor), **CAF** (currency), **GRI/PSS** (general rate increase/peak season), **low sulfur/IMO 2020 , congestion** surcharges , and **equipment imbalance.** In **land freight,** these include **drayage/chassis, rail/intermodal linehaul, port/terminal handling charges ,** and **last mile charges.** Transversely, these include **demurrage/detention, storage, insurance, tariffs ,** and **working capital** (UNCTAD, 2020; World Bank, 2020). In stress scenarios, small variations in **bunker/diesel** (EIA, 2021) and **schedule reliability** (Sea-Intelligence, 2021) produce **multiplicative effects** on the TLC, as they increase cycle times, require buffers and shift cargo to more expensive modes/practices (Chopra; Meindl, 2016).

The second step is to map freight **transmission mechanisms** to the **total cost of service.** As **lead times** and **dispersion** increase, **safety stock** and tied-up capital increase ,

carrying cost; when **OTIF** falls, **air shipments** and **redispatching** increase , increasing the cost of operations; when **receiving windows** are missed, **contractual penalties** and **lost sales** arise . The **area of the resilience triangle** (fall × duration) transforms this degradation into a measurable **economic loss ,** allowing **cents per TEU-mile** to be linked to P&L **margin points** (Sheffi, 2015; Ponomarov; Holcomb, 2009). Thus, scenario planning needs **to co-simulate** freight pricing, reliability, and tactical decisions (buffers, diversion, capacity options) to capture the **full effect.**

In the **ocean, bunker** shocks alter **BAF** in near-real time, but their net impact depends on the **equipment mix, routes ,** and flow **commuting : imbalanced** trades suffer additional **repositioning surcharges;** trades with **multiple transshipments** are more sensitive to **congestion** and prolonged **GRI** (UNCTAD, 2020; Notteboom; Rodrigue, 2021). In **sanctions/export control** scenarios , **"forbidden paths" create** longer routes, change **the energy intensity** of the chain, and shift the **slot allocation** balance between alliances, affecting **priority** and **rollover.** These effects require **response curves** per service to estimate **how much TLC increases** for each lost **reliability point .**

In **North American intermodal, drayage/chassis constraints** and **rail linehaul** act as **amplifiers** of the TLC. The lack of **chassis** increases **wait time** and **detention; driver shortages** and **hours-of-service rules** put pressure on **spot rates;** limited **rail slots** increase **transit time** and **variance** (USDOT, 2020; OECD/ITF, 2016). In peak scenarios, **transloads** from 40' to 53' and **transfers** between ramps add handling and risk of damage; however, when well-timed, they reduce the **cost per useful mile** over long distances. Models should capture this **trade-off** and test **triggers** to switch between **all-water East Coast** and **land-bridge West** Coast according **to TTR** and **incremental cost.**

A critical transmission vector is **demurrage/detention.** In systemic congestion, linear charging policies generate **injustice** and encourage box **hoarding ,** increasing **underutilization** and **premium freight; conditional** policies with **exemptions when the root cause is terminal/hinterland** reduce **dead costs** and free up **equipment (World** Bank, 2020; IAPH, 2020). In these scenarios, it is necessary to parameterize **alternative rules** and measure how much **TTR** and **TLC**
change when governance shifts from **uniform punishment** to **pro-fluidity incentives** (Drewry, 2021). When simulating, it is observed that a few dollars less in detention produces **hundreds of dollars** in **avoided loss** per container.

Energy connects geopolitics and freight to the FTA. **Bunker** and **diesel** are **correlated** in global shocks, and simultaneous spikes raise **BAF** and **road linehaul,** shifting the **cost frontier .**
between road and **rail/intermodal; jet-A** sets the **air cargo** price for contingency shipments (EIA, 2021; UNCTAD, 2020). Scenarios should include **price bands** with **tariff elasticities** by mode and modal shift **rules ,** so that the simulation captures when

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It is cheaper **to fly** part of the critical SKU mix than **to miss the sales window,** and when it is better **to stock up** for a few days than to pay **premium shipping.**

Another transmission channel is **compliance and tariffs. Sanctions and tariffs** reconfigure **BOMs** and **origins; export controls on** high-tech inputs create **indirect routes** or force **substitution of suppliers** with different **lead times** and prices, increasing costs and **quality risks** (UNCTAD, 2020; Notteboom; Rodrigue, 2021). The FTA must reflect **administrative costs** (licenses, audits, tariff classification), and **origin audit** overheads . (USMCA rules) and **scale losses** when the portfolio is fragmented to pursue **regulatory resilience.** In practice, **real options** (slots, gateways, suppliers) mitigate part of this cost when **triggers** activate previously qualified **replacement plans** (Simchi-Levi; Kaminsky; Simchi-Levi, 2008).

In **organizational terms,** TLC only enters decision-making when **metrics** and **processes** convert **logistical cents into margin points** and **S&OP/S&OE priorities. Control towers** They must present **incremental TLC by scenario** and **avoided loss** by measure (extended windows, off-dock, *multi-gateway,* capacity option), with **thresholds** that trigger actions without ad hoc debate (IAPH, 2020; ISO 22301, 2019). The **business case** ceases to be "expensive freight" and becomes **"preserved margin** and **reduced TTR,"** language that allows for rigorous **approval of resilience capex/opex** (Sheffi, 2015).

Finally, TLC modeling must incorporate **SKU/customer heterogeneity: time-sensitive** items have high **time value** and justify **premium** or **air freight; commoditized** items tolerate **strategic inventories** and longer **lead times . ABC curves for value and criticality,** coupled with **differentiated service policies,** prevent uniform solutions that **burn cash** without increasing resilience. In short, the TLC in these scenarios functions as a **unified dashboard** where freight, reliability, and tactical decisions converge to guide efficient mitigation **portfolios** (Chopra; Meindl, 2016; Sea-Intelligence, 2021).

4. Geopolitical risk matrices and design of alternative routes (gateways, *all-water,* land-bridge and *nearshoring)*

The construction of **geopolitical risk matrices** begins by **categorizing shocks** that affect US supply chains: (i) disputes and sanctions between major economies (US–China; Russia; Iran), **(ii) bottlenecks** at **chokepoints** (Suez, Panama, Strait of Malacca, Taiwan Strait, Bab el-Mandeb), **(iii) climate** and **labor** events affecting gateways (Gulf hurricanes, coastal strikes), **(iv) cyber incidents** and **compliance** (export controls), and **(v) energy fluctuations** that reprice modes (UNCTAD, 2020; USDOT, 2020). For each class, **probability, impact, detectability ,** and **warning time** are assessed , defining **signposts** and **triggers** for activating alternative routes (Sea-Intelligence, 2021; ISO 22301, 2019). The objective is not to predict the event, but **to pre-agree on viable responses .**

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In the **trans-Pacific,** alternatives range from **West Coast land-bridge** (LA/LB, Oakland, Tacoma/ Seattle) to **all-water East/Gulf** (NY/NJ, Savannah, Charleston, Houston). Congestion/labor shocks in LA / **LB** can trigger **all-water diversions** to the East, at the cost of **greater ocean traffic** and **lower land variance;** shocks in **Panama** or **Atlantic cyclones** can rebalance in favor of the **West Coast** with deep **rail linehaul** (USDOT, 2020; Notteboom; Rodrigue, 2021). The optimal choice depends on relative **TTR , total freight ,** and **rail capacity;** therefore, matrices should **co-simulate** ports, canals, and **rail slots** to determine **target shares** per gateway under different regimes.

In the **transatlantic** and **Americas,** the **Eastern/Gulf** (NY/NJ, Norfolk, Savannah, Houston) and **Gulf/Mexico** gateways form the backbone. **Hurricanes** and **floods** impose seasonal **risk windows ; security policies** in the Gulf can reduce **throughput; congestion** in NY/NJ redistributes calls to the **Southeast.** In parallel, **nearshoring** to **Mexico** and **Central America**
adds **land optionality** (truck/rail under USMCA) and reduces exposure to **ocean chokepoints,** at the expense of **institutional risks** and cross- **border capacity** (OECD/ITF, 2016; USDOT, 2020). Headquarters must quantify when **transferring SKUs** nearshore preserves **margin** and **service level.**

On the **global chokepoint** axis , **Suez** and **Panama** are dominant variables. The **partial closure of Suez** induces **circumnavigation ,** saving **days** and **bunker costs,** affecting **Asia-East US routes** via **the Med/Atlantic;** restrictions in **Panama** shift services to **LA/LB** or **all-water via Suez/Cape Town,** increasing **variance** (Notteboom; Rodrigue, 2021; UNCTAD, 2020). **Signals** such as **lake levels** in Panama, **AIS traffic ,** and **anchorage queues** act as **diversion triggers.** In critical scenarios, **transshipment** via **Canada** (Prince Rupert/Vancouver) with **rail** to the Midwest emerges as **a bypass** with competitive TTR.

The **China+1 matrix** considers **partial** production relocation to **Vietnam, India, Indonesia, Mexico ,** and **the US.** This relocation changes **ocean times, tariff profiles, regulatory risk ,** and **modal capacity.** For example, **an all-water India-US trade** via **Suez** is sensitive to shocks in this canal but reduces exposure to **LA/LB; a Mexico-US trade** reduces **capital costs** due to **a short lead time** but requires **border infrastructure** and **security** (USDOT, 2020; UNCTAD, 2020). The matrix quantifies **FTAs** and **TTRs** by SKU based on **origin mix** and guides transition **schedules** with **ramp-ups** and **bridge stocks.**

Labor and climate risks require seasonal maps and **mitigation windows.** Coastal **strikes** present **signals** (negotiation impasses) that allow for **pre-positioning inventory** or **advance bookings; hurricane seasons** in the Gulf and Atlantic trigger **extended gate hours, off-dock ,** and **priority** for **time-sensitive** cargo (USDOT, 2020; ISO 22301, 2019). **Digital twins** with **weather** layers and **union calendars** enable **stress tests** with **playbooks.**
structured, reducing **latency** and **loss.**

Cyber and compliance comprise the cross-cutting layer. Attacks on **TOS/PCS** and logistics **pipelines** can disrupt services without physical damage; **export controls** reconfigure **BOMs** and **routes .**

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overnight (IAPH, 2020; UNCTAD, 2020). The matrices include cyber **hardening** (redundancy, disconnected backups) and "clean" compliance **paths** for critical SKUs, with **documentation ready. Triggers:** vulnerability alerts, regulatory changes, sectoral incidents.

Finally, **alternative route design** is **a portfolio approach ,** not **a silver bullet.** Geopolitical matrices prescribe **target participations** per gateway and **diversion options** with **clear thresholds** (decrease in **schedule reliability, queue, bunker/diesel),** combining **contractual optionalities** (slots, *box pools),* **structural buffers** (off-dock/dry ports), and **data** (PCS/control towers) to **reduce TTR** and **protect margin** (Simchi-Levi; Kaminsky; Simchi-Levi, 2008; Sea-Intelligence, 2021; USDOT, 2020). Success is measured by the area of the triangle of reduced **resilience ,** sustained OTIF, and **stabilized TLC** in adverse scenarios.

5. Mitigation portfolios and *real options:* efficient buffer frontiers, multi-gateway and elastic contracts

The formulation of a **mitigation portfolio** is based on the principle that no single intervention dominates in all scenarios; the objective is to compose an **efficient portfolio** that minimizes the **area of the resilience triangle** (downturn × duration) at the lowest possible cost of capital. In practice, this involves combining **physical buffers** (bridge stocks, deliberate idle capacity), **structural buffers ,** and (multi-gateway, dry ports/off-dock, modal redundancy), **informational buffers (PCS,** control towers, arrival forecasts), and **contractual options** (capacity reservations, *box pools,* deviation clauses) that can be **activated by** previously agreed triggers (SHEFFI, 2015; CHOPRA; MEINDL, 2016). The optimal portfolio differs by SKU and corridor, as **the value of time, substitutability ,** and **criticality** vary substantially between product families and regions (PONOMAROV; HOLCOMB, 2009).

The **real options** lens helps price decisions in the context of **freight volatility** and **geopolitical shocks:** paying a **premium** today for a **slot option** or a **multi-gateway contract** is analogous to acquiring the right, not the obligation, to exercise capacity when **signposts** signal reliability degradation or cost *spikes* (SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008; CHRISTOPHER, 2016). The expected value of this option increases with the **underlying volatility** (bunker/diesel, *schedule reliability)* and the **disruption cost,** so that highly critical SKUs justify higher premiums. This approach disciplines the conversation with finance, as it translates "TTR reduction" into **avoided loss** per dollar invested, comparable to the CAPEX of warehouses, yards, and automation (SHEFFI, 2015).

Physical buffers have merit where **lead time** is long, replacement is low, and **arrival uncertainty** dominates; however, they immobilize **working capital** and are at **risk of obsolescence,** requiring strict governance via **ABC curves** and **continuous review** policies (CHOPRA; MEINDL, 2016). In contrast, **structural buffers** — such as **multi-gateway** and **off-dock** — preserve **operational optionality** with lower loading costs, as long as **standards**

technical aspects (packaging, labeling, EDI/API) make the replacement **plug-and-play** (OECD/ ITF, 2016; WORLD BANK, 2020). The *trade-off* between "stock" and "structure" is, therefore, contingent on the risk profile and the **elasticity of** transportation available in each corridor (NOTTEBOOM; RODRIGUE, 2021).

In **port and intermodal environments** subject to **congestion,** the portfolio should include **short-term tactics** (extended windows, yard reslotting, SLA/time value prioritization) that reduce backlogs quickly, and **medium-term interventions** (dry ports, seasonal rail contracts, regional *box pools)* that reduce **variance** without excessively increasing fixed costs (WORLD BANK, 2020; IAPH, 2020). For the **long term, modular** capabilities
(phased berths, selective automation, scalable rail corridors) avoid **rigidity** and allow growth in blocks, keeping **TTR** under control in repeated shocks (IVANOV; DOLGUI, 2020). Efficiency arises from the **complementarity** between time horizons.

The **contractual** dimension of the portfolio organizes **who pays what, when, and why. Contingency SLAs** with **objective triggers** (drop in *schedule reliability,* docking queues, *truck turn time,* used/planned *rail slot)* activate **capacity reservations, multi-gateway diversions ,** and **conditional demurrage/detention exemptions,** reducing litigation and **decision-making latency** (SEA-INTELLIGENCE, 2021; IAPH, 2020). In severe scenarios, **reliability indexing** and ***gain-sharing* mechanisms** align incentives to recover service faster, as part of the **bonus/ penalty** is converted into **operational actions** (extra windows, additional trains) that compress the **resilience triangle** (WORLD BANK, 2020; CHRISTOPHER, 2016).

Corridor **digital twins** —coupling **DES/SD/ABM** with **AIS/TOS/PCS** data —serve to create efficient portfolio **frontiers :** for each combination of **physical/structural buffers** and **contractual options, TTS/TTR, OTIF, demurrage/detention ,** and **TLC** are estimated under stress trajectories (IVANOV; DOLGUI, 2020). By plotting **impact/cost curves,** decision-makers identify "leverage points" (e.g., +1 train/day reduces TTR by 22%; +1 night window reduces *truck turntime* by 18%; +X% of *box pool* reduces *freight premium* by Y), replacing opinions with simulated **evidence** (SHEFFI, 2015). This discipline facilitates **CAPEX/OPEX** approval and prioritizes **quick wins.**

The portfolio must also reflect **spatial heterogeneity** and **seasonality.** During **peak periods** (harvests, *peak season),* measures such as **dynamic scheduling, valley bands, off-dock pickup ,** and **seasonal rail contracts** have greater **elasticity ;** off-peak periods, **equipment pools** and **coordinated repositioning** capture access gains, mitigating **underutilization** and container **imbalances** (UNCTAD, 2020; DREWRY, 2021). On **the geopolitical map,** portfolios with **targeted holdings** by gateway and **origin mix** (China+1, nearshoring) reduce **risk correlations** and shorten **lead times,** protecting the **FTA** under sanctions and energy shocks (USDOT, 2020; NOTTEBOOM; RODRIGUE, 2021).

Ultimately, the portfolio's **go/no-go** should be governed by **risk limits** and **resilience targets. Operational VaR** and **Expected Shortfall** of service indicators (OTIF, *backlog clearing)* define **tolerable ranges; TTR/TTS targets** by SKU and corridor become **restrictions of the**

S&OP/S&OE thresholds (LPG below X%, bunker/diesel above the band) **trigger** the exercise of options and **reconfigure** flows according to the *playbook* (ISO 22301, 2019; SEA-INTELLIGENCE, 2021). Thus, the portfolio is more than a set of ideas: it is an **operable mechanism** that transforms **signals** into **action** with clear *timing* and responsibilities.

6. Governance, Data, and Activation *Signposts :* From PCS and Control Towers to Trigger-Driven S&OP

Resilience governance translates scenarios and portfolios into **decision-making routines.** At the core, **Port Community Systems (PCS)** and **Digital Single Windows** consolidate **operational and documentary data** (ETA/ETD, queues, productivity, inspections) using **open standards** and **secure APIs,** reducing **information asymmetry** and **downtime** (IAPH, 2020; OECD/ITF, 2016). On this layer, **interorganizational control towers integrate** TOS /**WMS/TMS/rail slots** and **reliability indicators** (GLP/Sea-Intelligence), displaying trigger-driven **KPIs/KRIs.** (e.g., *truck turn time* > X, *dwell* > Y, docking queue > Z) that trigger **playbooks** pre-authorized — open windows, prioritize critical loads, activate **off-dock,** recommend **multi-gateway diversion** (WORLD BANK, 2020; SEA-INTELLIGENCE, 2021).

The definition of **signposts** —precursor signals that anticipate the approach of a scenario—is the link between **intelligence** and **operations.** Examples include **persistent declines** in *schedule reliability* by alliance/service, bunker /**diesel** out-of-band (EIA) **spikes , and abnormal increases. anchoring time** at critical gateways (AIS), **regulatory alerts** on **sanctions/export controls, restrictions in Panama/Suez** and ***driver shortage*** **indicators** (vacancies, *spot rates* road users) (USDOT, 2020; UNCTAD, 2020; SEA-INTELLIGENCE, 2021). Each signpost needs a **numerical threshold, responsible person ,** and **default action;** without this engineering, detection becomes curiosity and not **decision** (ISO 22301, 2019).

Data dictionaries and **calculation methodologies** are essential for **comparisons** make sense: *dwell* by cargo/service type, *truck turn time* by window, planned vs. actual *rail utilization ,* delay **dispersion ,** error **persistence** by service, simulated **TTR** by intervention (OECD/ITF, 2016). **Reconciliation cycles** (TOS ÿ PCS ÿ WMS/TMS) and **audit logs** support **accountability** and limit contractual disputes, especially when **reliability indexing** and **conditional demurrage/detention exemptions** come *into* play (IAPH, 2020; WORLD BANK, 2020). **Data quality** is not an accessory: it is **operational capacity.**

Trigger-driven **S&OP/S&OE orchestration** connects the control tower to **execution.** In **S&OP, TTR/ TTS targets, VaR limits ,** and target gateway and mode **mixes** are defined by SKU; in **S&OE, playbooks** are applied when **signposts** cross thresholds— **exercising** slot options, **migrating** *sailing* to *all-water* or *land-bridge,* **pre-positioning inventory, activating** dry ports, and **extending windows** (SIMCHI-LEVI; KAMINSKY; SIMCHI-LEVI, 2008; CHRISTOPHER, 2016).

Short rituals (daily briefings, weekly *war rooms)* avoid **decision-making latency** and **pace** adaptation, with post-event **AARs** generating **continuous improvement** (ISO 22301, 2019; SHEFFI, 2015).

The **contractual-informational** layer requires **pre-authorization** to function in minutes, not weeks: who can **divert** X% of the portfolio? Who **accesses** capacity reserves? Who **signs** conditional *demurrage* exemption ? What **data** is published to **audit** the decision? Without these **rights of action** and paper **limits ,** the control tower becomes an observation panel (IAPH, 2020; WORLD BANK, 2020). **Segregation of duties** and **compliance** preserve integrity, especially in environments with **alliances** and integrated operators (OECD/ITF, 2016).

Cyber resilience and **continuity** are cross-cutting conditions. **Disconnected** TOS/PCS backups, **contingency plans** for manual *fallback ,* and periodic **restoration tests** reduce the chance that a **cyber incident** will neutralize governance at the worst possible time (ISO 22301, 2019). In geopolitical scenarios, **disruption targets** may include digital infrastructure; therefore, **redundant telemetry, degraded access ,** and alternative **communication protocols** (radio, SMS) must be included in the **playbook,** with regular **training** (SHEFFI, 2015).

Selective transparency with the ecosystem strengthens the legitimacy of decisions. Public turnaround /**dwell/ reliability dashboards** with explicit methodology, **barometers** Periodic (IAPH) and corridor **performance reports** support **accountability** and **alignment** among actors, reducing the temptation of **particular solutions** that concentrate gains and socialize losses (IAPH, 2020; WORLD BANK, 2020). In concentrated markets, data **aggregation/delay** preserves competition while providing **common coordinates** for action (OECD/ITF, 2016; HARALAMBIDES, 2019).

Training closes the loop: teams capable of reading **signposts,** operating **digital twins,** and translating **metrics** into **decisions** are as important as cranes and rails. **Training** programs for **queues and networks, logistics contracts, S&OP/S&OE ,** and **risk analysis** must be continuous, with **living labs** in terminals and **simulations** integrated into the routine (CHRISTOPHER, 2016; IVANOV; DOLGUI, 2020). Bonuses tied to **reduced TTR, preserved OTIF ,** and **reduced *demurrage/ detention*** align behavior with the goal of **measurable resilience (SHEFFI,** 2015).

Finally, **governance, data, and signposts** only create value when **anchored to budgets and targets. KPIs/ KRIs are** included in the **annual plan, and portfolios** receive funding with **phase gates.** conditioned on **TTR reduction** and **avoided loss,** and **quarterly reviews** adjust **thresholds** as the environment changes (USDOT, 2020; ISO 22301, 2019). Thus, the system ceases to depend on “operational heroes” and begins to operate under an **Operational Resilience Regime** reproducible, where **signals** become **actions** and **actions** become auditable **metrics .**

7. Empirical Validation and Learning: Evidence from US Corridors Under Geopolitical Shock and Freight Volatility

The usefulness of scenario planning depends on its **external validity:** models and *playbooks* need to replicate observed patterns and explain residual variability in **TTR, OTIF ,** and **TLC** in real shocks. In the **trans-Pacific,** the combination of **declining *schedule reliability,* docking queues ,** and **chassis/driver constraints** generated simultaneous degradations in **turnaround** and **dwell,** an effect predicted by **interconnected queue** models and **percolation when** multiple nodes operate with ÿ ÿ 1 (Sea-Intelligence, 2021; World Bank, 2020; Ivanov; Dolgui, 2020). In retrospective tests, digital twins that coupled **AIS/TOS/PCS data** and **bunker/diesel bands** reproduced **backlog curves** and **delay windows** with acceptable error, reinforcing the adequacy of the framework for mitigation **decisions** (Notteboom; Rodrigue, 2021; UNCTAD, 2020).

In **the West ÿ Interior/Midwest land-bridge, rail capacity** and adherence to drayage **schedules explained** differences in TTR between **similar ocean freight routes ,** validating the premise of **intermodal coupling** and the need for **inland KRIs** (truck turn time, utilized/ planned rail *slot)* in the resilience dashboard (USDOT, 2020; OECD/ITF, 2016). In *what-if exercises,* the activation of **extended windows** and **additional trains** anticipated by **signposts** (decrease in reliability due to alliance; increase in *anchor time)* reduced **backlog clearing** by tens of hours, with significant **avoided losses** in the **FTA** (Sea-Intelligence, 2021; World Bank, 2020). These results support the inclusion of **operational triggers** in contracts and S&OE.

In the **all-water scenario for the East Coast/Gulf,** scenarios combining **pressured Panama** and **Atlantic weather** showed that **real gateway diversification** mitigates risk but only preserves **margin** when accompanied by **off-dock/dry ports** and time-value prioritization **SOPs .** Otherwise, the ocean gain is offset by **spillback** at yards and *gates* (Notteboom; Pallis, 2020; World Bank, 2020). Simulations indicated that technical **standards** (packaging, labeling, EDI/API) reduce the *ramp-up* of alternative routes by weeks, justifying **low-CAPE** investments with a high impact on **TTR** (OECD/ITF, 2016; Christopher, 2016).
This finding reinforces the thesis of **modularity** as a lever of resilience.

In **freight costs,** the **energy ÿ tariffs ÿ FTA** link was validated by parameterizing **BAF/diesel/ jet-A** with **EIA** series and elasticities by mode; simultaneous *spikes* increased **premium freight,** activating *playbooks* that migrated part of the **road ÿ rail/intermodal** mix and **ocean ÿ air** for **time-sensitive** SKUs , with a positive impact on **OTIF** and **preserved revenue** (EIA, 2021; UNCTAD, 2020; Chopra; Meindl, 2016). The **opportunity cost** of not activating the option—measured by **the area of the resilience triangle** —exceeded the premium paid for **capacity options,** corroborating the **economics of** volatility options (Simchi-Levi; Kaminsky; Simchi-Levi, 2008; Sheffi, 2015).

In the contractual dimension , case studies with **reliability indexing** and **contingency SLAs** have shown a reduction in **litigation** and **decision latency** when **metric dictionaries** and

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APIs were coded ex-ante in **PCS;** the absence of these elements generated **version disputes** that postponed actions during the critical window (IAPH, 2020; World Bank, 2020). The **conditional exemption from** ***demurrage/ detention*** when the root cause was terminal/hinterland accelerated **box turnover** and improved **equipment availability,** reducing **premium freight rates** in congested corridors (UNCTAD, 2020; Drewry, 2021). These results support **pro-fluidity policies** in a crisis.

In **nearshoring** (USMCA), pilots with **a partial mix of origins** showed a decrease in **working capital** and **lead time,** with lower **TTR** under ocean shocks, but with **institutional risks** and **cross-border restrictions** that require **an interoperable Single Window** and a reliable rail **slot ;** the **net advantage** emerged when **compliance** and **capacity** were resolved through **bilateral agreements** and **modular investments** (USDOT, 2020; OECD/ITF, 2016). The lesson is that **risk substitution** must be accompanied by **standards and governance** to avoid exchanging one bottleneck for another (Haralambides, 2019; Rodrigue, 2020).

In **cyber resilience,** sectoral incidents have shown that **disconnected backups** and ***fallback*** **plans** preserve **governance** when **PCS/TOS** are affected; tabletop exercises have reduced **restoration time** and **information loss,** keeping **S&OE** operational in degraded mode (ISO 22301, 2019; Sheffi, 2015). In terms of scenarios, the cyber layer was integrated as a **cross-cutting shock** with **alternative communication** triggers **and** degraded **decision rights,** validating the principle that **data** is critical infrastructure for resilience (IAPH, 2020; World Bank, 2020).

Regarding **value measurement,** *dashboards* that translated **TTR/OTIF** and **freight** into **TLC** and **Operational VaR** accelerated **CAPEX/OPEX approval ,** shifting the discourse from "additional cost" to **"avoided loss** and **preserved margin,"** a language that bridges operations and finance (Ponomarov; Holcomb, 2009; Sheffi, 2015). In the quarterly revaluation, portfolios with **structural buffers** (multi-gateway, off-dock) and **contractual options** dominated arrangements based solely on **physical inventories,** especially for SKUs with **high time value.**

(Christopher, 2016; Sea-Intelligence, 2021). The empirical evidence, therefore, aligns with the model's theses.

Finally, **institutional learning** —via **AARs** and ***playbook*** **versions** —proved crucial to maintaining **dynamic viability:** teams that ran **simulations** and **trials**
reduced **timing errors** in option activation and improved **backlog clearing** in subsequent waves (ISO 22301, 2019; Ivanov; Dolgui, 2020). The *insight* is clear: scenarios are **practiced capability,** not documentation; their effectiveness grows with **deliberate repetition, multilateral governance ,** and **public metrics.**

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8. Roadmap and governance: from proof of ***concept* to resilience operational regime**

The **roadmap** begins with a **materiality diagnosis:** mapping **critical corridors, A/B SKUs by time value, probable bottlenecks** (ports, rail, *drayage,* compliance) and **energy dependencies,** producing a **risk register** with **owners, KRIs/KPIs** and **TTR/TTS targets.** (USDOT, 2020; ISO 22301, 2019). In parallel, define *axes* **of uncertainty** for the scenario portfolio (geopolitics; freight/energy; intermodal capacity) and **storylines** coherent decisions that feed the **digital twin** (Wack, 1985; Schoemaker, 1995). The result is a **decision map** that links **triggers** to **options** (deviation, capacity reserves, windows) and **buffers** (bridge stocks, off-dock).

In **Phase 1 (0–90 days),** build the **minimum viable dashboard:** integrate **AIS/ETA, TOS, PCS, WMS/TMS ,** and **rail data** to display **reliability by service, queue/anchorage, turnaround/dwell, truck turn time,** rail slot, and **container availability,** with **a metric dictionary** and agreed-upon **data SLA** (IAPH, 2020; World Bank, 2020). In parallel, **prototype** the **digital twin** of a pilot corridor (e.g., trans-Pacific ÿ Midwest) and run **baseline scenarios,** calibrating parameters with 2018–2021 series (Sea-Intelligence, 2021; Ivanov; Dolgui, 2020). This basis allows for **quick decisions** at the first seasonal peak.

In **Phase 2 (90–180 days),** institutionalize **an interorganizational control tower** with **preauthorized decision rights** and codified **playbooks : open windows, prioritize critical loads, activate off-dock, divert X%** to an alternative gateway when **thresholds** are crossed (ISO 22301, 2019; Christopher, 2016). In contracts, implement **contingency SLAs, reliability indexing ,** and **capacity options** for relevant services and gateways; in equipment, negotiate regional **pools/box interchange** with **neutral governance** (Drewry, 2021; UNCTAD, 2020). The emphasis is on **reducing decision latency** in shocks.

In **Phase 3 (6–12 months),** scale **structural buffers: dry ports, retroport terminals, chassis cohorts ,** and **seasonal rail contracts,** prioritizing corridors where **TTR** is most sensitive to **yard evacuation** and **linehaul** (World Bank, 2020; OECD/ITF, 2016). In parallel, standardize **packaging/labeling/messaging** for **plug-and-play substitutability** between gateways and operators, reducing **requalification time** and diversion **costs** (Christopher, 2016; Notteboom; Pallis, 2020). This phase consolidates **true geographic redundancy.**

In **Phase 4 (12–24 months),** invest in **modular capacity** and **selective automation** where twin **response curves** indicate **a high marginal gain** in **TTR** per unit of capital: **phased berths, additional STS, partial yard automation, scalable rail corridors, and** off **-dock logistics zones** (Ivanov; Dolgui, 2020; World Bank, 2020). Linking **availability payments** to **contingency SLAs** reduces demand risk and accelerates *payback,* transforming resilience into **a bankable asset** (Sheffi, 2015). Governance should include **phase gates** and **quarterly reviews** for **avoided loss.**

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The **regulatory framework** involves **Single Window, harmonization of consents** and **public goals** (turnaround, *dwell,* reliability), with **open data standards** and **periodic barometers** to reduce **political noise** and align incentives (USDOT, 2020; IAPH, 2020; OECD/ITF, 2016). In **cross-border cooperation** (USMCA), prioritize document **interoperability** and **rail slots;** in **chokepoints** (Panama/Suez), incorporate hydrological and **AIS traffic** signposts to diversion *playbooks* (Notteboom; Rodrigue, 2021; UNCTAD, 2020). The common thread is that **data and rules** are as critical as **cranes and rails.**

In **human capital,** create **training paths** for reading **signposts,** operating **digital twins, options contracts ,** and **trigger-based S&OP/S&OE;** run monthly **simulations** and **AARs** post-peak to fix learning (Christopher, 2016; ISO 22301, 2019). **Bonuses** linked to **reduced TTR, preserved OTIF ,** and **reduced demurrage/detention** align behavior with **measurable resilience** (Sheffi, 2015). The desired culture favors **data discipline, pre-authorized execution ,** and **multilateral cooperation.**

In **finance,** incorporate **Operational VaR** and **Expected Shortfall** of service into the **budget cycle** and approve **mitigation portfolios** for **avoided loss;** structure **parametric insurance** and **capacity options** with **verifiable triggers** (LPG, queues, *dwell),* and use the twin to **price** the **rational premium** (Ponomarov; Holcomb, 2009; Sea-Intelligence, 2021). Reports to the board should display **efficient boundaries** between **physical inventory, structural buffers ,** and **options,** with **TTR/OTIF targets** as constraints, not *nice-to-haves* (Simchi-Levi; Kaminsky; Simchi-Levi, 2008; Sheffi, 2015).

Finally, the **resilience operational regime** is consolidated when **signals become actions** and **actions become metrics** under **predefined governance: signposts** monitored by the tower; **triggers** triggering **playbooks; auditable data** in **PCS/Single Window; contracts** with **SLAs/options/ conditional waivers; AARs** feeding back into models; and **public goals** aligning ecosystems (World Bank, 2020; IAPH, 2020; ISO 22301, 2019). This cycle closes the gap between **anticipation** and **execution,** reducing **the area of the resilience triangle** and stabilizing **TLC.** in adverse scenarios (Notteboom; Rodrigue, 2021; Sea-Intelligence, 2021).

Conclusion

The research developed throughout this article has argued that **scenario planning** is more than a narrative exercise: it is an **operational mechanism** for reducing the exposure of U.S. supply chains to **geopolitical disruptions** and **freight cost volatility,** provided it connects plausible storylines to **quantitative models** and **decision triggers** coupled with S&OP/S&OE. By combining **discrete-event simulation, system and agent dynamics** with **Monte Carlo ,** and indicators such as **TTS/TTR, OTIF, Operational VaR, and avoided loss,** we demonstrate that the practical utility of scenarios increases when their assumptions are anchored in **measurable signalposts** (persistent decline in *schedule reliability,* bunker/diesel *spikes ,* AIS queuing/ anchoring, regulatory changes), all translated into **playbooks .**

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preauthorized (Wack, 1985; Schoemaker, 1995; Sheffi, 2015; Sea-Intelligence, 2021; USDOT, 2020).

In terms of **risk phenomenology,** we show that apparently exogenous shocks — Trade sanctions, *chokepoint events,* strikes, and extreme weather events—all materialize in **port and intermodal links** as **queues, productivity losses, and increased variance,** triggering delay **percolation** in networks with high centrality and undersized buffers. **Interconnected queuing** theory and **network science** explain why small productivity drops at multiple nodes (ÿÿ1) produce **superlinear** backlog growth, expanding the **area of the resilience triangle** and degrading the **FTA** beyond what historical averages suggest (Ivanov; Dolgui, 2020; World Bank, 2020; Notteboom; Rodrigue, 2021). When well-constructed, the scenario anticipates this critical regime and determines **where to decouple** and **when to deviate.**

In the **economic** vector , the breakdown of freight into its **tariff components** (base rate, BAF/CAF, GRI/PSS, congestion, *equipment imbalance)* and land costs (drayage/chassis, rail linehaul, *terminal handling, last mile)* reveals **transmission mechanisms** up to the **Total Landed Cost,** including via **safety stocks, working capital, contingency shipments ,** and **contractual penalties** for missed windows. The integration **of energy ÿ tariff ÿ TLC** —with bands for bunker/diesel/jet-A and elasticities by mode— proved critical for valuing **real options** (capacity reservations, multi-gateway, *box pools)* and for dimensioning **structural buffers** that preserve **margin** when reliability degrades (UNCTAD, 2020; EIA, 2021; Chopra; Meindl, 2016; Sheffi, 2015).

At the geographic-strategic level , the **risk matrices** by corridor (trans-Pacific, trans-Atlantic, Gulf/Americas) and by **chokepoints** (Panama, Suez, Strait of Malacca, Taiwan Strait) indicated that **real diversification of** gateways combined with **off-dock/dry ports** and **technical standardization** (packaging, labeling, EDI/APIs) creates **operational optionality** with competitive total cost. In parallel, **China+1** and **USMCA nearshoring** reduce exposure to critical ocean routes, but only deliver net resilience when accompanied by **document interoperability** and **cross-border capacity** (USDOT, 2020; OECD/ITF, 2016; Notteboom; Pallis, 2020; Rodrigue, 2020). Scenarios allow **sequencing** these transitions and **pricing ramp-ups.** with *bridging stock.*

Data governance has emerged as the infrastructure for predictability. **Port Community Systems** and **Single Digital Windows** have reduced **information latency** and **noise** between stakeholders, enabling **inter-organizational control towers with pre-authorized rights** to open windows, prioritize critical loads, trigger **off-dock** operations , and recommend **diversions,** all while relying on **metric dictionaries, secure APIs ,** and **audit logs.** Experience gathered from port barometers and performance reports indicates that communities with **open data standards** and **regular** KPI publications weathered the 2019–2021 volatility better, making **SLAs indexed**

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reliability and operationalizable and auditable **conditional demurrage/detention exemptions** (IAPH, 2020; World Bank, 2020; OECD/ITF, 2016).

In the **contractual-incentive domain,** we argue and illustrate that **contingency SLAs** with **objective triggers, capacity options ,** and ***gain-sharing*** **mechanisms** convert scenarios into actionable **operational insurance ,** reducing **decision latency** and **litigation** in critical windows. In severe scenarios, **interorganizational container pools** and ***box interchange*** **agreements** have proven effective in mitigating **equipment imbalances** and underutilization, freeing up slots for paying cargo and reducing **premium freight** —a result reinforced by root-cause-based **demurrage/detention** policies (Drewry, 2021; Clarksons Research, 2021; UNCTAD, 2020). Contractual consistency, therefore, enhances process engineering.

The **value** analysis showed that decisions need to shift from “cost per TEU” to **avoided loss.** and **reduced** TTR per unit of capital, comparing **efficient frontiers** between **physical inventories, structural buffers ,** and **contractual options. Digital twins** calibrated with 2018–2021 series were crucial in translating **response curves** (e.g., +1 train/day, +1 overnight window, X% *box pool)* into **preserved OTIF, reduced demurrage/detention ,** and **stabilized TLC—** a language that brings boards and operations closer together and facilitates **CAPEX/ OPEX** approval with **Operational VaR** and **Expected Shortfall** criteria (Ponomarov; Holcomb, 2009; Sheffi, 2015; Ivanov; Dolgui, 2020).

In the **implementation roadmap,** we advocate a four-phase path: **(i)** minimum viable panel and pilot corridor twin; **(ii)** control tower with **rights of action, playbooks ,** and **contracts** with SLAs/indexing/options; (iii) scaling of **structural buffers** (dry ports, off-dock, seasonal rail contracts) and **standardization** for **plug-and-play replacement; (iv)** investments in **modular capacity and selective automation** anchored in **availability payments** and TTR targets. The guiding principle is a **Resilience Operational Regime** where **signals become actions** and **actions become metrics** under **predefined governance** (ISO 22301, 2019; USDOT, 2020; World Bank, 2020).

The **public and transboundary** dimension is inseparable from private performance: **disclosed performance targets, open data standards, regulatory harmonization ,** and **interoperability agreements** (customs, phytosanitary, security) reduce the "border effect," shorten systemic **TTR ,** and create **legitimacy** for prioritization in scarcity. In parallel with the **climate agenda,** investments in **adaptation** (physical infrastructure) and **decarbonization** (shore power, yard electrification) have shown **reliability co-benefits,** reducing unplanned outages and increasing **energy redundancy** (Haralambides, 2019; World Bank, 2020; UNCTAD, 2020). Resilience, therefore, aligns with sustainability as **an ecosystem advantage.**

As **a research and practice agenda,** there are three tracks: **(a)** standardized methods for **pricing real options in** logistics contracts and *box pools* under freight volatility and geopolitical regimes; **(b)** operational integration of **digital twins** into **S&OP/S&OE,** with **signposts**

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automated and **feedback** by *After Action Reviews;* **(c) ecosystem resilience** metrics that capture distributive and **reputational effects** beyond the firm, including under climate and cybernetic perspectives. The expected marginal gain lies in **reducing the gap** between *insight* and **execution** by standardizing how we prioritize **buffers, data, and contracts** (Sea-Intelligence, 2021; IAPH, 2020; ISO 22301, 2019).

In short, **planning scenarios** for North American chains means **designing responses** before the crisis: **where to integrate** to control what cannot fail, **how to modularize** to preserve **optionality, when to activate** options and **how much to invest** to **reduce TTR** and **preserve margin.** under shocks. The proposed framework— **metric, modeled, and governed** —replaces improvisation with **resilience engineering,** transforming geopolitical and tariff variability into **manageable risk** and, by extension, into **repeatable competitive advantage** for companies and corridors that adopt it (Christopher, 2016; Notteboom; Rodrigue, 2021; USDOT, 2020; Sheffi, 2015).

References

CHOPRA, S.; MEINDL, P. *Supply Chain Management: Strategy, Planning, and Operation.* 6. ed. Boston: Pearson, 2016.

CHRISTOPHER, M. *Logistics & Supply Chain Management.* 5. ed. Harlow: Pearson, 2016.

CLARKSONS RESEARCH. *Container Intelligence Quarterly.* London: Clarksons Research, 2021.

DREWRY. *Container Forecaster.* London: Drewry Maritime Research, 2021.

EIA – US ENERGY INFORMATION ADMINISTRATION. *Short-Term Energy Outlook.* Washington, DC: EIA, 2021.

HARALAMBIDES, HE Gigantism in container shipping, ports and global logistics: a time-lapse into the future. *Maritime Economics & Logistics,* vol. 21, p. 1–60, 2019.

IAPH – INTERNATIONAL ASSOCIATION OF PORTS AND HARBORS. *COVID-19 Port Economic Impact Barometer.* Antwerp: IAPH, 2020.

ISO. *ISO 22301:2019 — Security and Resilience — Business Continuity Management Systems — Requirements.* Geneva: ISO, 2019.

IVANOV, D.; DOLGUI, A. Viability of intertwined supply networks: extending the supply chain resilience angles. *International Journal of Production Research,* vol. 58, n. 10, p. 2904–2915, 2020.

RCMOS – Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.

NOTTEBOOM, T.; PALLIS, A. Port Economics, Management and Policy: COVID-19 and the impact on ports. Reports/briefs, 2020.

NOTTEBOOM, T.; RODRIGUE, J.-P. Port congestion and the destabilization of supply chains in 2020/2021. *Maritime Economics & Logistics,* 2021.

OECD/ITF – INTERNATIONAL TRANSPORT FORUM. *Policies to Enhance Intermodal Connectivity and Performance.* Paris: OECD Publishing, 2016.

PONOMAROV, SY; HOLCOMB, MC Understanding the concept of supply chain resilience. *The International Journal of Logistics Management,* vol. 20, no. 1, p. 124–143, 2009.

RODRIGUE, J.-P. *The Geography of Transport Systems.* 4th ed. New York: Routledge, 2020.

SCHOEMAKER, PJH Scenario planning: a tool for strategic thinking. *Sloan Management Review,* vol. 36, no. 2, p. 25–40, 1995.

SEA-INTELLIGENCE MARITIME ANALYSIS. *Global Liner Performance (GLP) Report.* Copenhagen: Sea-Intelligence, 2021.

SHEFFI, Y. *The Power of Resilience: How the Best Companies Manage the Unexpected.* Cambridge, MA: MIT Press, 2015.

SIMCHI-LEVI, D.; KAMINSKY, P.; SIMCHI-LEVI, E. *Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies.* 3rd ed. Boston: McGraw-Hill/Irwin, 2008.

UNCTAD – UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT. *Review of Maritime Transport 2020.* Geneva: UNCTAD, 2020.

USDOT – UNITED STATES DEPARTMENT OF TRANSPORTATION. *National Freight Strategic Plan.* Washington, DC: USDOT, 2020.

WACK, P. Scenarios: Shooting the rapids. *Harvard Business Review,* vol. 63, n. 6, p. 139–150, 1985.

WORLD BANK; IHS MARKIT. *Container Port Performance Index 2020.* Washington, DC: World Bank, 2020.